

## CLAIMS

We claim:

1           1.       A method for forming a thermal barrier coating system in communication  
2       with at least a portion of at least one substrate, the method comprising:  
3           presenting said at least one substrate to a chamber, wherein said chamber has a  
4       down stream pressure,  $P_c$ , with an operating range from about 0.0001 Pa to about 150 Pa;  
5           depositing a bond coat on at least a portion of at least one said substrate;  
6           presenting at least one evaporant source to said chamber;  
7           presenting at least one carrier gas stream to said chamber, wherein said at least one  
8       carrier gas stream is generated from at least one nozzle;  
9           impinging at least one said evaporant source with at least one energetic beam in  
10       said chamber to generate an evaporated vapor flux in a main direction respective for any  
11       of said evaporant sources impinged by said energetic beam, said at least one evaporant  
12       source is disposed in said nozzle;  
13           said at least one carrier gas stream has a pressure ratio in the operating range from  
14       about 1.01 to about 10,000,000;  
15           said substrate having a temperature approximately equal to or greater than a  
16       melting point of said substrate;  
17           said at least one evaporant source generates said evaporated vapor flux and an  
18       evaporation rate in the range of about 0.00001 g/min to about 100,000 g/min; and  
19           deflecting at least one of said generated evaporated vapor flux by at least one of  
20       said carrier gas stream, wherein said carrier gas stream is essentially parallel to the main  
21       direction and substantially surrounds said evaporated flux, wherein said evaporated vapor  
22       flux at least partially coats at least one said substrate.

1           2.       The method of claim 1, wherein said substrate having a temperature in the  
2       range of about 25° C to about 1,250° C.

1           3.       The method of claim 1, wherein:

2       said down stream pressure,  $P_c$ , has an operating range from about 0.1 Pa to about  
3   20 Pa;

4       said at least one carrier gas stream has a pressure ratio in the operating range from  
5   about 1.01 to about 1,000; and

6       said substrate having a temperature approximately equal to or greater than a  
7   melting point of said substrate.

1       4.     The method of claim 3, wherein said substrate having a temperature in the  
2   range of about 900° C to about 1,250° C.

1       5.     The method of claim 1, wherein:

2       said down stream pressure,  $P_c$ , has an operating range from about 1 Pa to about 20  
3   Pa;

4       said at least one carrier gas stream has a pressure ratio in the operating range from  
5   about 11 to about 1,000; and

6       said substrate having a temperature approximately equal to or greater than a  
7   melting point of said substrate.

1       6.     The method of claim 5, wherein said substrate having a temperature in the  
2   range of about 900° C to about 1,250° C.

1       7.     The method of any one of claims 1, 2, 3, 4, 5 and 6, wherein said at least  
2   one substrate is held stationary during the deposition process.

1       8.     The method of any one of claims 1, 2, 3, 4, 5 and 6, wherein said at least  
2   one substrate is moved during at least a portion of the deposition process.

1       9.     The method of claim 8, wherein the movement comprises at least a partial

2 rotation or multiple rotations.

1 10. The method of any one of claims 1, 2, 3, 4, 5 and 6, wherein said at least  
2 one evaporant source has a diameter in the range of about 0.1 inch to about 10 inch.

1 11. The method of claim 10, wherein said at least one evaporant source has a  
2 diameter in the range of about 0.5 inch to about 1 inch.

1 12. The method of anyone of claims 3 and 4, wherein said evaporation rate in  
2 the range of about 0.1 g/min to about 100 g/min.

1 13. The method of any one of claims 12, wherein said at least one evaporant  
2 source has a diameter in the range of about 0.1 inch to about 10 inch.

1 14. The method of claim 13, wherein said at least one evaporant source has a  
2 diameter in the range of about 0.5 inch to about 1 inch.

1 15. The method of anyone of claims 5 and 6, wherein said evaporation rate in  
2 the range of about 0.1 g/min to about 100 g/min.

1 16. The method of any one of claims 15, wherein said at least one evaporant  
2 source has a diameter in the range of about 0.1 inch to about 10 inch.

1 17. The method of claim 16, wherein said at least one evaporant source has a  
2 diameter in the range of about 0.5 inch to about 1 inch.

1           18.     The method of anyone of claims 1, 2, 3, 4, 5 and 6, wherein said evaporant  
2 source comprises at least one of Zirconium, Hafnium, mullite, alumina, silica, any oxide  
3 ceramic, ceria, zirconate, garnet, lanthanum aluminate, titania, any carbide, silicide or  
4 combination thereof.

1           19.     The method of anyone of claims 1, 2, 3, 4, 5 and 6, wherein said evaporant  
2 source comprises at least one of any ceramic material or combination thereof.

1           20.     The method of anyone of claims 1, 2, 3, 4, 5 and 6, wherein said  
2 evaporants have substantially the same chemical composition relative to one another.

1           21.     The method of anyone of claims 1, 2, 3, 4, and 6, wherein said evaporants  
2 have different chemical composition relative to one another.

1           22.     A method for forming a thermal barrier coating system, the method  
2 comprising:  
3           presenting a substrate to a chamber, wherein said chamber has a down stream  
4 pressure,  $P_c$ , with an operating range from about 5 Pa to about 50 Pa;  
5           depositing a bond coat on at least a portion of at least one said substrate;  
6           presenting at least one evaporant source to said chamber;  
7           presenting at least one carrier gas stream to said chamber, wherein said at least one  
8 carrier gas stream is generated from at least one nozzle;  
9           impinging at least one said evaporant source with at least one energetic beam in  
10 said chamber to generate an evaporated vapor flux in a main direction respective for any  
11 of said evaporant sources impinged by said energetic beam, said at least one evaporant  
12 source is disposed in said nozzle;  
13           said at least one carrier gas stream has a pressure ratio in the operating range from  
14 about 1 to about 100;

15 said substrate having a temperature in the range of about 15° C and about 1,250°  
16 C;

17 said at least one evaporant source generates said evaporated vapor flux and an  
18 evaporation rate in the range of about 0.1 g/min to about 100 g/min;

19 deflecting at least one of said generated evaporated vapor flux by at least one of  
20 said carrier gas stream, wherein said carrier gas stream is essentially parallel to the main  
21 direction and substantially surrounds said evaporated flux, wherein said evaporated vapor  
22 flux at least partially coats at least one said substrate;

23 said chamber further includes a substrate bias system capable of applying a DC or  
24 alternating potential to at least one of said substrates;

25 impinging said at least one of said generated vapor flux and at least one of said  
26 carrier gas stream with a working gas generated by at least one hollow cathode arc plasma  
27 activation source to ionize said at least one of said generated vapor flux and at least one of  
28 said carrier gas stream; and

29 attracting said ionized generated vapor flux and said carrier gas stream to a  
30 substrate surface by allowing a self-bias of said ionized gas and vapor stream or said  
31 potential to pull the ionized stream to said substrate.

1 23. The method of claim 22, wherein said substrate having a temperature in  
2 the range of about 300° C and about 1,250° C.

1 24. The method of claim 22, wherein said substrate having a temperature in  
2 the range of about 600° C and about 1,250° C.

1 25. The method of claim 22, wherein said substrate having a temperature in  
2 the range of about 900° C and about 1,250° C.

1 26. The method of any one of claims 22, 23, 24 and 25, wherein said at least

2 one evaporant source has a diameter in the range of about 0.1 inch to about 10 inch.

1 27. The method of claim 26, wherein said at least one evaporant source has a  
2 diameter in the range of about 0.5 inch to about 1 inch.

1 28. The method of claim 22, said generated electrons from said hollow cathode  
2 source is regulated for direction through variations in the quantity of working gas passing  
3 through said hollow cathode source.

1 29. The method of claim 22, wherein the distance between said cathode source  
2 and said generated evaporated vapor flux is regulated for ionization of the entire  
3 generated evaporated vapor flux.

1 30. The method of any one of claims 22, 23, 24 and 25, wherein said at least  
2 one substrate is held stationary.

1 31. The method of any one of claims 22, 23, 24 and 25, wherein said at least  
2 one substrate is moved during at least a portion of the vapor flux coating .

1 32. The method of claim 31, wherein the movement comprises at least a partial  
2 rotation or multiple rotations.

1 33. The method of anyone of claims 22, 23, 24 and 25, wherein said evaporant  
2 source comprises at least one of Zirconium, Hafnium, mullite, alumina, silica, any oxide  
3 ceramic, ceria, zirconate, garnet, lanthanum aluminate, titania, any carbide, silicide and/or  
4 other ceramics, or combination thereof.

1           34.     The method of anyone of claims 22, 23, 24 and 25, wherein said evaporant  
2     source comprises at least one of any ceramic material or combination thereof.

1           35.     The method of anyone of claims 22, 23, 24 and 25, wherein said  
2     evaporants have substantially the same chemical composition relative to one another.

1           36.     The method of anyone of claims 22, 23, 24 and 25, wherein said  
2     evaporants have different chemical composition relative to one another.

1           37.     The method of claim 1 or 22, wherein said energetic beam comprises at  
2     least one of electron beam source, laser source, heat source, ion bombardment source,  
3     highly focused incoherent light source, microwave, radio frequency, EMF, or any  
4     energetic beam that break chemical bonds, or any combination thereof.

1           38.     The method of claim 1 or 22, wherein said communication with said  
2     substrate is direct or indirect.

1           39.     An apparatus for applying a thermal barrier coating system in  
2     communication with at least a portion of at least one substrate, said apparatus comprising:  
3         a chamber, wherein said chamber has a down stream pressure,  $P_c$ , with an  
4     operating range from about 0.0001 Pa to about 150 Pa;  
5         at least one evaporant source disposed in said chamber, said at least one evaporant  
6     source generates said evaporated vapor flux and an evaporation rate in the range of about  
7     0.00001 g/min to about 100,000 g/min;  
8         at least one carrier gas stream provided in said chamber, wherein said at least one  
9     carrier gas stream is generated from at least one nozzle, said at least one carrier gas stream  
10    has a pressure ratio in the operating range from about 1.01 to about 10,000,000; and  
11    at least one energetic beam, said energetic beam:

12                   impinging at least one said evaporant source with at least one energetic  
13                   beam in said chamber to generate an evaporated vapor flux in a main direction  
14                   respective for any of said evaporant sources impinged by said energetic beam,  
15                   deflecting at least one of said generated evaporated vapor flux by at least  
16                   one of said carrier gas stream, wherein said carrier gas stream is essentially  
17                   parallel to the main direction and substantially surrounds said evaporated flux,  
18                   wherein said evaporated vapor flux at least partially coats at least one said  
19                   substrate, and  
20                   said substrate having a temperature approximately equal to or greater than  
21                   a melting point of said substrate.

1           40.    The apparatus of claim 39, wherein said substrate having a temperature in  
2           the range of about 25° C to about 1,250° C.

1           41.    The apparatus of claim 39, wherein  
2           said down stream pressure,  $P_c$ , has an operating range from about 0.1 Pa to about  
3           20 Pa;  
4           said at least one carrier gas stream has a pressure ratio in the operating range from  
5           about 1.01 to about 1,000; and  
6           said substrate having a temperature approximately equal to or greater than a  
7           melting point of said substrate.

1           42.    The apparatus of claim 41, wherein said substrate having a temperature in  
2           the range of about 900° C to about 1,250° C.

1           43.    The apparatus of claim 39, wherein  
2           said down stream pressure,  $P_c$ , has an operating range from about 1 Pa to about 20  
3           Pa;  
4           said at least one carrier gas stream has a pressure ratio in the operating range from



5 about 11 to about 1,000; and  
6 said substrate having a temperature approximately equal to or greater than a  
7 melting point of said substrate.

1 44. The apparatus of claim 43, wherein said substrate having a temperature in  
2 the range of about 900° C to about 1,250° C.

1 45. The apparatus of any one of claims 39, 40, 41, 42, 43 and 44, wherein said  
2 at least one substrate is held stationary during the deposition process.

1 46. The apparatus of any one of claims 39, 40, 41, 42, 43 and 44, wherein said  
2 at least one substrate is moved during at least a portion of the deposition process.

1 47. The apparatus of claim 46, wherein the movement comprises at least a  
2 partial rotation or multiple rotations.

1 48. The apparatus of anyone of claims 39, 40, 41, 42, 43 and 44, wherein said  
2 evaporant source comprises at least one of Zirconium, Hafnium, mullite, alumina, silica,  
3 any oxide ceramic, ceria, zirconate, garnet, lanthanum aluminate, titania, any carbide,  
4 silicide or combination thereof.

1 49. The apparatus of anyone of claims 39, 40, 41, 42, 43 and 44, wherein said  
2 evaporant source comprises at least one of any ceramic material or combination thereof.

1 50. The apparatus of anyone of claims 39, 40, 41, 42, 43 and 44, wherein said  
2 evaporants have substantially the same chemical composition relative to one another.

1           51.     The apparatus of anyone of claims 39, 40, 41, 42, 43 and 44, wherein said  
2     evaporants have different chemical composition relative to one another.

1           52.     An apparatus for applying a thermal barrier coating system in  
2     communication with at least a portion of at least one substrate, said apparatus comprising:  
3           a chamber, wherein said chamber has a down stream pressure,  $P_c$ , with an  
4     operating range from about 5 Pa to about 50 Pa;

5           at least one evaporant source disposed in said chamber, said at least one evaporant  
6     source generates said evaporated vapor flux and an evaporation rate in the range of about  
7     0.1 g/min to about 100 g/min;

8           at least one carrier gas stream provided in said chamber, wherein said at least one  
9     carrier gas stream is generated from at least one nozzle, said at least one carrier gas stream  
10    has a pressure ratio in the operating range from about 1 to about 100;

11          at least one energetic beam, said energetic beam:

12               impinging at least one said evaporant source with at least one energetic  
13          beam in said chamber to generate an evaporated vapor flux in a main direction  
14          respective for any of said evaporant sources impinged by said energetic beam,

15               deflecting at least one of said generated evaporated vapor flux by at least  
16          one of said carrier gas stream, wherein said carrier gas stream is essentially  
17          parallel to the main direction and substantially surrounds said evaporated flux,  
18          wherein said evaporated vapor flux at least partially coats at least one said  
19          substrate, and

20               said substrate having a temperature approximately equal to or greater than  
21          a melting point of said substrate; and

22               a substrate bias system capable of applying a DC or alternating potential to at least  
23          one of said substrates; and

24               at least one hollow cathode arc source generating a low voltage beam, said at least  
25          one hollow cathode arc source:

26               impinging said at least one of said generated vapor flux and at least one of  
27          said carrier gas stream with a working gas generated by at least one said hollow

28 cathode arc plasma activation source to ionize said at least one of said generated  
29 vapor flux and at least one of said carrier gas stream; and  
30 attracting said ionized generated vapor flux and said carrier gas stream to a  
31 substrate surface by allowing a self-bias of said ionized gas and vapor stream or  
32 said potential to pull the ionized stream to said substrate.

1 53. The apparatus of claim 52, wherein said substrate having a temperature in  
2 the range of about 300° C and about 1,250° C.

1 54. The apparatus of claim 52, said generated electrons from said hollow  
2 cathode source is regulated for direction through variations in the quantity of working gas  
3 passing through said hollow cathode source.

1 55. The apparatus of claim 52, wherein the distance between said cathode  
2 source and said generated evaporated vapor flux is regulated for ionization of the entire  
3 generated evaporated vapor flux.

1 56. The apparatus of claim 39 or 52, wherein said energetic beam comprises at  
2 least one of electron beam source, laser source, heat source, ion bombardment source,  
3 highly focused incoherent light source, microwave, radio frequency, EMF, or any  
4 energetic beam that break chemical bonds, or any combination thereof.

1 57. The apparatus of claim 39 or 52, wherein said communication with said  
2 substrate is direct or indirect.